TIMING AND SOURCES OF POSTGLACIAL GROUNDWATER DISCHARGE NEAR THE GLACIAL LIMIT OF THE JAMES LOBE OF THE LAURENTIDE ICE SHEET, SOUTH DAKOTA

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ABSTRACT

Deposits of tufa, travertine, and carbonate cements are scattered north of the Missouri River within 20 km of the known glacial limit of the James Lobe of the Laurentide continental ice sheet. These deposits drape and cement late Wisconsin glacial sediments and are being studied to investigate potential constraints on conceptual models of groundwater flow associated with glacial advance and retreat. Five study sites are distributed on the south and west sides of the James Lobe near Yankton and Pierre, respectively. Modern springs with high dissolved-ion contents (conductivities >2000 μS/cm) discharge at or near all sites. Deposits near Yankton are poorly exposed in the eastern alluvial scarp of the James River valley and consist of calcite-cemented glacial sediment and porous tufa cut by banded travertine veins. Modern springs have δ^2H and $\delta^{18}O$ values (-63 and -8.8‰, respectively) that are consistent with recharge of modern precipitation in shallow aquifers, along with elevated U concentrations (19–31 ppb) indicative of oxidizing conditions. Deposits near Pierre are better exposed and include a variety of tufa with abundant iron and manganese oxides. Springs associated with these deposits have much lower δ^2H values (-129 to -139‰) and indicators of reducing conditions including abundant Fe-Mn hydroxide precipitates and relatively low U concentrations (0.6-1.4 ppb). These springs have affinities with deep artesian groundwater with Pleistocene isotopic signatures and likely reflect upward leakage into shallow aquifers.

Yankton-area travertines have high U/Th and precise U-series ages ranging from 13.0 to 10.5 ka for main-stage vein material with late-stage vug-fillings as young as 5.8 ka. Both initial U isotopic compositions and $\delta^{13}C$ and $\delta^{18}O$ values vary slightly but systematically with age. Nevertheless, all calcite $\delta^{18}O$ values are consistent with modern discharge rather than with values expected for glacial meltwater. Dating of Pierre-area tufas is complicated by lower U concentrations and U/Th due to high Fe-Mn oxide abundances, but also indicate late-Pleistocene to Holocene ages. Calcite $\delta^{18}O$ values in these materials show a much larger range and are consistent with formation from mixtures of both deep and shallow groundwater sources.

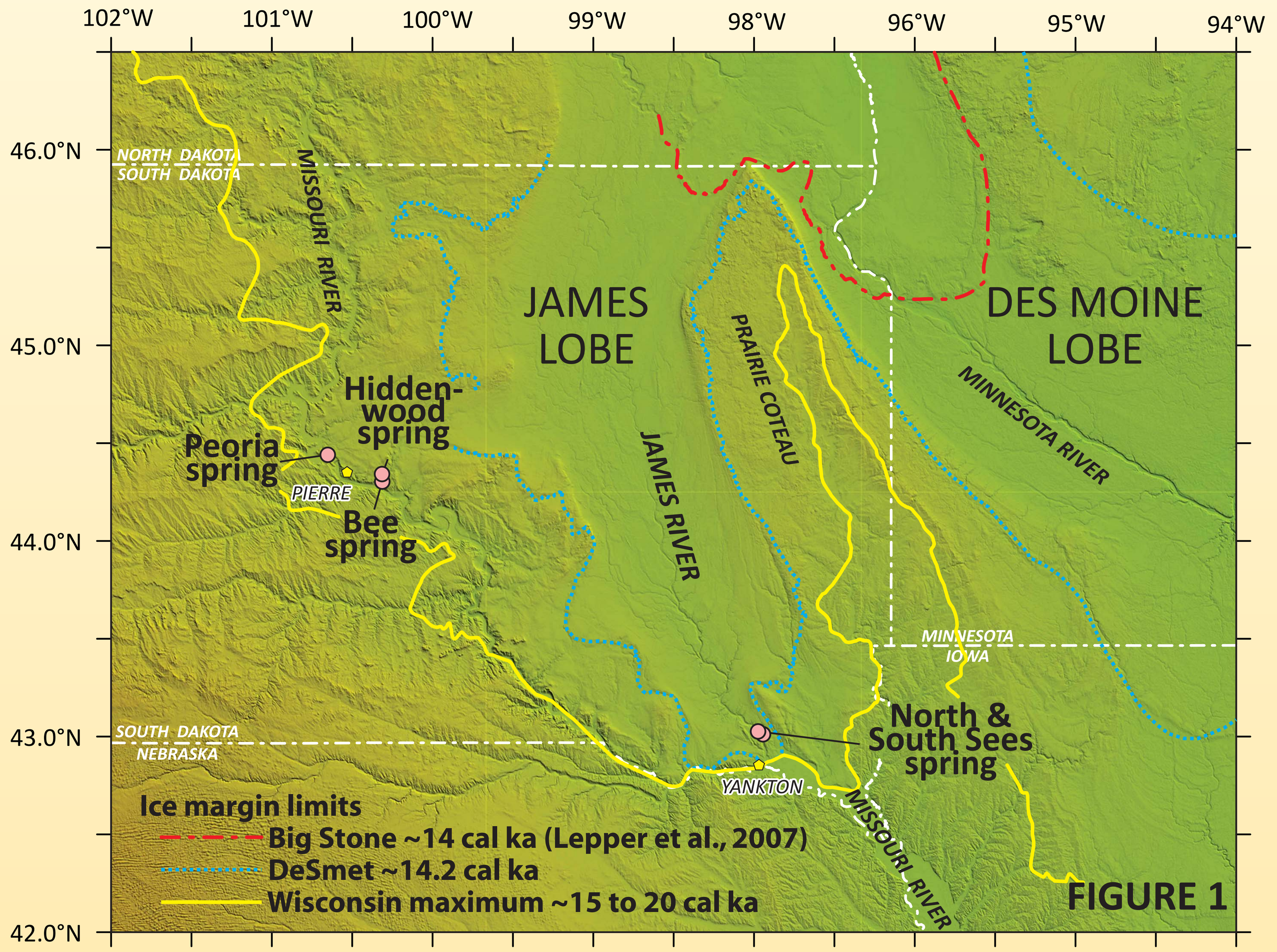


FIGURE 1

INTRODUCTION

The James Lobe of the Laurentide ice sheet occupied much of the eastern half of South Dakota north of the Missouri River during parts of the late Pleistocene (Fig. 1). The last advance occurred as recently as 14 to 15 ka with ice occupying the James River lowland as far south as the Missouri River.

Groundwater discharge deposits are present in several places within the limits of ice cover and present an opportunity to investigate relations between groundwater flow and the timing of advances and retreats of continental glaciers.

Deposits are predominantly calcite allowing determination of ages by U-series and radiocarbon dating methods and isotopic compositions ($^{234}U/^{238}U$, $\delta^{18}O$, $\delta^{13}C$, $^{87}Sr/^{86}Sr$), which can be used to evaluate the compositions of groundwater at the time of discharge.

Because modern springs are present at all sites, deposits provide a means of seeing how groundwater flow systems have evolved over time.

OBJECTIVES

Determine a geochronological framework for discharge deposits

Evaluate the likely water sources for deposits (glacial meltwater, local ground-water, regional groundwater)

Evaluate post-glacial changes in groundwater compositions

Evaluate the role of the James Lobe ice sheet on groundwater dynamics

SAMPLE SITES AND MATERIALS

Pierre Area; West side of James Lobe

- Peoria spring mound near Oahe Dam)
- Bee spring mound (near Canning, SD)

Spring mounds are several meters thick and consist of crudely layered, porous to dense tufa with abundant Fe-Mn oxides.

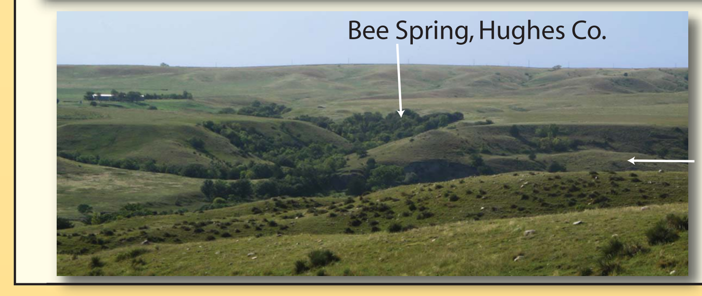
Geologic relations with associated tills and underlying Pierre Shale are fairly well exposed.

Yankton Area; Southern end of James Lobe

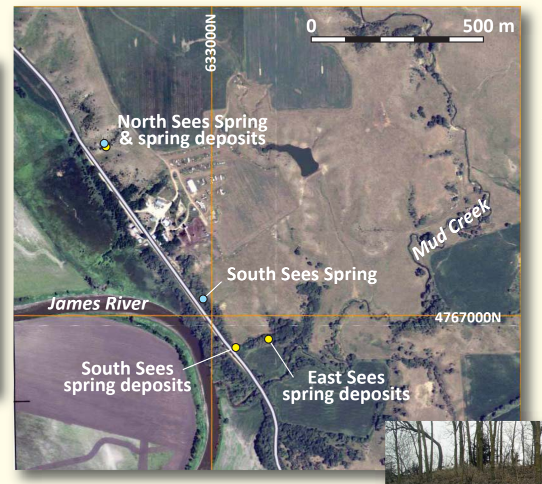
- Sees spring mound (NE Jim River road)

Several discharge areas with scattered outcrops of carbonate-cemented gravelly till cut by numerous coarse, sparry calcite veins.

Geologic relations with associated glacial deposits and underlying bedrock are poorly exposed.



Medicine Knoll Creek Valley

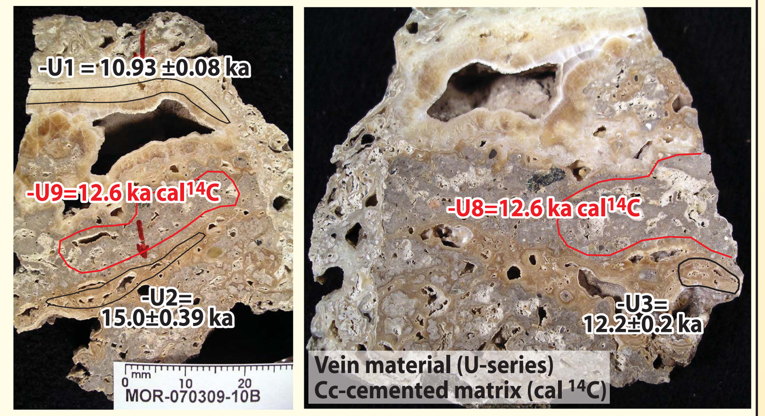


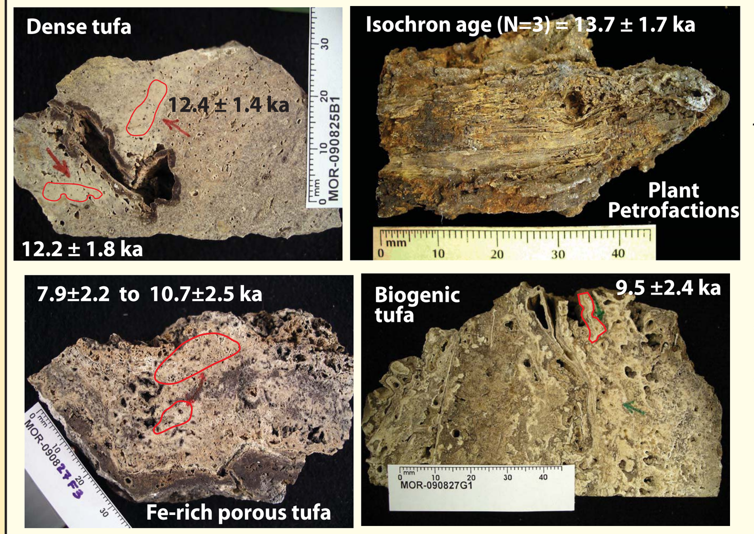
Satellite map of Sees spring area, Yankton Co.

GEOCHRONOLOGICAL FRAMEWORK

Sees Spring Deposits: Carbonate vein material has high U contents (3–6 μg/g) and U/Th concentration ratios (>100).

- Resulting $^{230}Th/U$ ages are analytically robust and range between 15 and 5.8 ka, with ±~0.2 ka uncertainties.
- Median age for 21 analyses of dense vein material = 11.4 ka with 95% confidence interval of 11.1 to 12.3 ka.
- Late-stage pendant-like material deposited in open vugs have younger ages between 5.8 and 8.1 ka





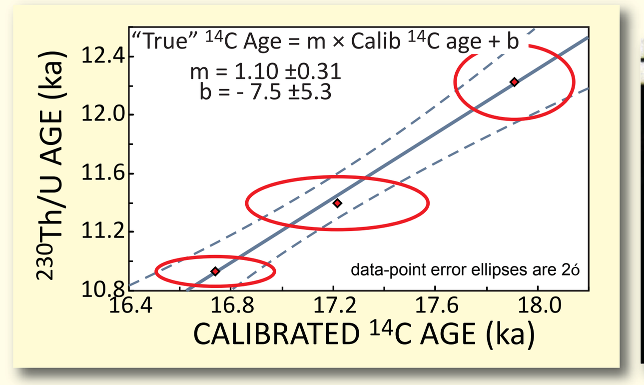
Pierre-Area Deposits: Porous to dense tufas have low U contents (<0.3 μg/g) and U/Th concentration ratios (<10).

- Resulting $^{230}Th/U$ ages require large corrections for detrital ^{230}Th contents and have large propagated uncertainties (typically 1.5–3 ka).
- Post-depositional U mobility is present in many samples.
- Best estimates for $^{230}Th/U$ ages range from 7.9 to 13.7 ka. Median age for 10 analyses of best-behaved material is 11.1 ka with 95% confidence interval of 9.3 to 12.8 ka.

Radiocarbon Results:

Sees Spring: ^{14}C used to test age of matrix not datable by U-series. Reservoir effect on ^{14}C ages were evaluated by analyzing clean vein material with known U-series ages. Resulting ages for matrix are similar to ages of cross-cutting veins (12.5–12.6 ka)

Peoria Spring: Terrestrial snails present in fine-grained sediment at base of spring mound and in lower-most tufas. One shell dated by ^{14}C yielded a calibrated age of 24.5 ±0.4 ka. Corrections for potential reservoir effects have not been evaluated yet.



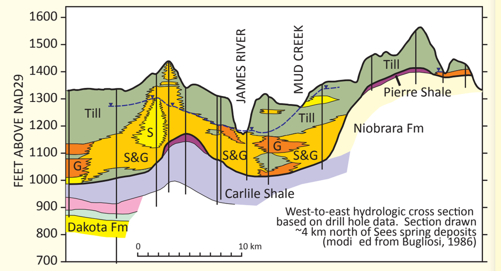
SOURCES OF WATER

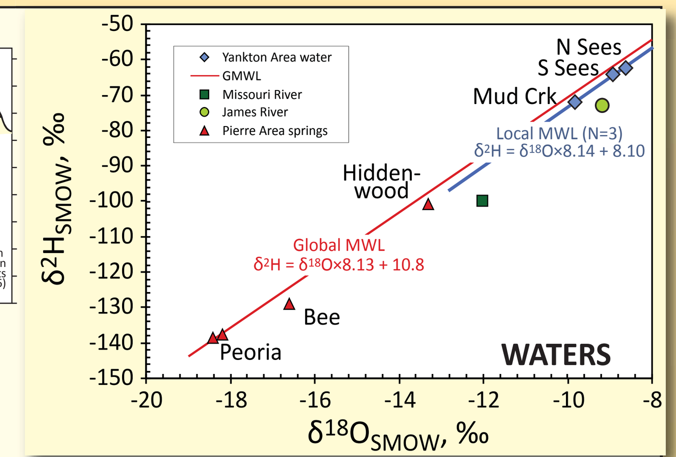
Sources of modern groundwater:

- Shallow aquifers in glacial deposits
- Shallow bedrock aquifers (Niobrara & Dakota)
- Deep bedrock aquifers (Pz brines)
- Surface water

Additional Sources of paleo spring water

- Recharge from glacial meltwater (basal flow, pro-glacial lakes)





Compositions of modern spring discharge:

Location	TDS, mg/L	δ^2H, ‰	$\delta^{18}O$, ‰	$\delta^{87}Sr$, ‰	$^{234}U/^{238}U$ AR	U, μg/L	Fe	Redox
Pierre-Area Springs	1400 to 1700	-101 to -138	-13.3to -18.4	-1.3 to -1.8	1.5 to 1.6	0.6 to 10	mod. to high	Reducing
Sees Springs	1700 to 1900	-62 to -64	-8.6 to -8.9	-0.3 to 0.2	1.3 to 1.5	19 to 31	low to mod.	Oxidizing

All springs discharge from glacial deposits, but may represent upward leakage from bedrock aquifers.

- Sees spring waters are more consistent with post-glacial (heavy δ^2H & $\delta^{18}O$), locally recharged, oxidizing water that obtained Sr from flow within tills (Lower James-Missouri aquifer; Bugliosi, 1986)
- Peoria spring water is more consistent with glacially recharged (light δ^2H & $\delta^{18}O$), reducing water that may have Sr from Permian evaporites ($\delta^{87}Sr$ of ~-1.5 to -2.0‰; e.g., Minnelusa-Madison aquifer; Hamilton, 1986)
- Bee & Hiddenwood springs are consistent with mixtures of shallow and deep groundwater

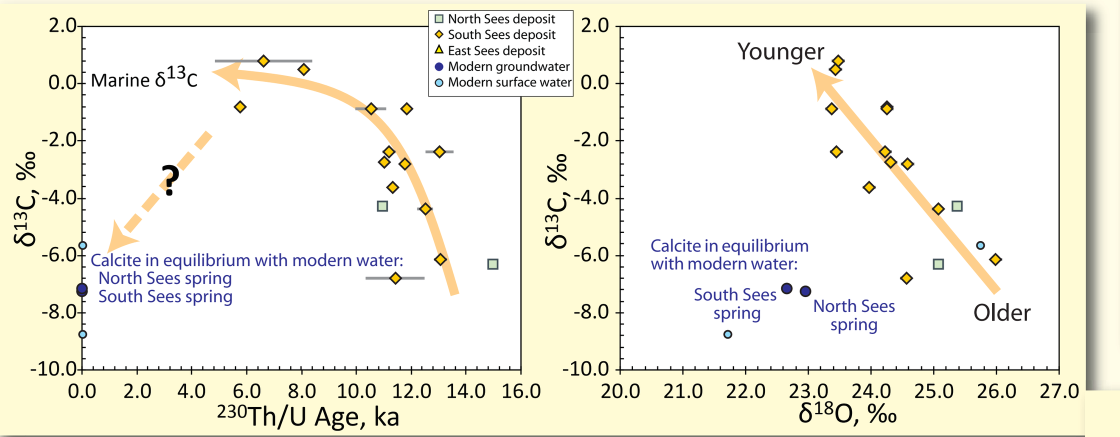
RADIOGENIC AND STABLE ISOTOPE COMPOSITIONS

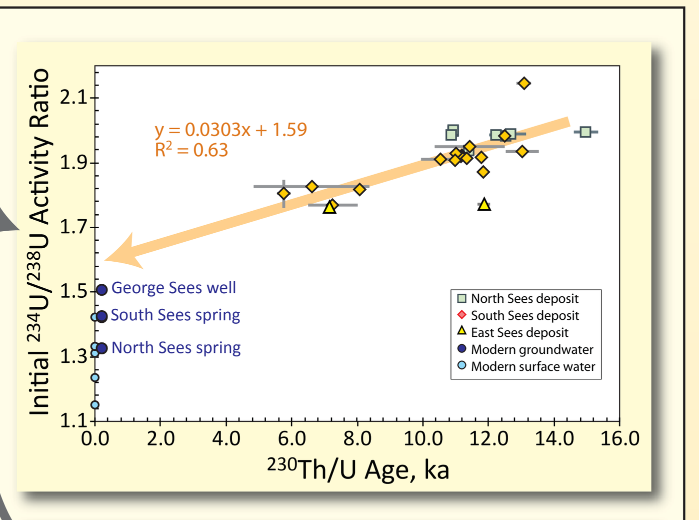
Isotopic evolution at Sees Spring:

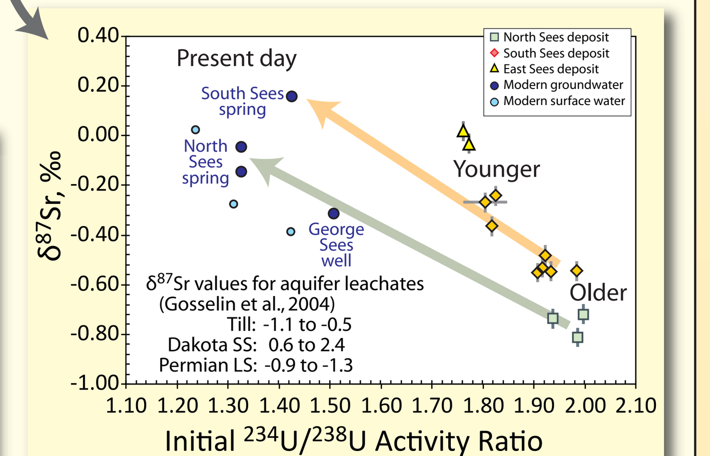
Oldest calcite has highest initial $^{234}U/^{238}U$ AR. Younger material has small, but significant, differences forming a trend toward modern groundwater values.

Similar trends with time between oldest calcite and modern water are observed for $\delta^{87}Sr$. Values are broadly consistent with glacial till sources rather than seawater or Dakota Sandstone sources.

Oldest calcite has lowest $\delta^{13}C$ and highest $\delta^{18}O$. The 2‰ shift in $\delta^{18}O$ data is consistent with a ~10°C shift in mean T between ~13 to 6 ka. $\delta^{13}C$ is consistent with either (1) a shift from early C3 plants (trees & shrubs) to later C4 plants (grasses), or (2) increasing amounts of C from marine sources with time. Sr data to not support latter hypothesis.





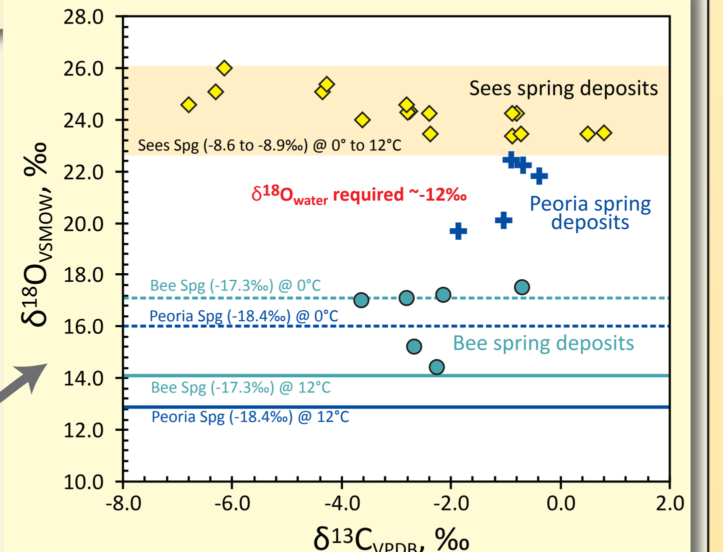


Isotopic Compositions of Pierre-area discharge deposits:

Low U contents and U/Th preclude precise dating and determination of initial $^{234}U/^{238}U$ AR. ^{14}C & Sr analyses are pending.

Calcites have a more limited range of $\delta^{13}C$ than Sees spring calcites with $\delta^{13}C$ values closer to marine signatures.

$\delta^{18}O$ values for Bee calcites are compatible with modern spring water ($\delta^{18}O$=-17.3‰) and depositional temperatures between 0 and 12°C. $\delta^{18}O$ values for Peoria calcites are not consistent with water discharging from modern Peoria spring and require less negative $\delta^{18}O$ values (e.g., ~-12‰ instead of -18‰). Data suggest that glacial meltwater was not present in the aquifer discharging at 12 to 14 ka.



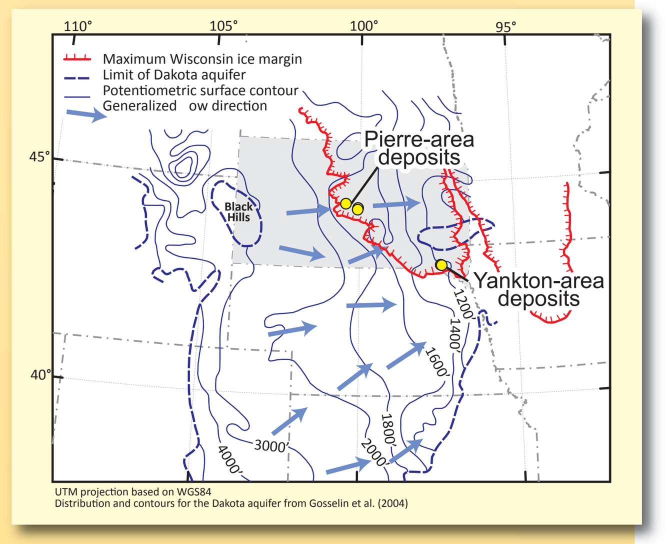
CONCLUSIONS

Paleospring deposits record a history of groundwater discharge interpreted to have initiated after final glacial retreat:

- ~13 to 14 ka in Yankton Co.; coeval or somewhat earlier in Pierre area

Yankton-area deposits (Sees springs) likely have a shallow source of groundwater within late-Wisconsin-age glacial deposits. Groundwater compositions evolved in response to post-glacial environmental changes.

Pierre-area deposits (Peoria, Bee, Hiddenwood springs) likely have a deeper groundwater source (Dakota or Minnelusa-Madison aquifers) that may or may not initially have had a meltwater component. At some time after ~11 ka, recharge that entered aquifers farther to the west (?) during the Pleistocene reached discharge areas.



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